SPICE: Connecting stellar feedback and cosmic reionisation

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Tracing imprints of different modes of stellar feedback

- How much do stellar/gas/radiative observables of high redshift galaxies depend on feedback models?
- Do we understand the degeneracies in the schemes we choose?
- HST/ALMA already asked questions, JWST piled on, have we explored the phase space enough to answer these questions?

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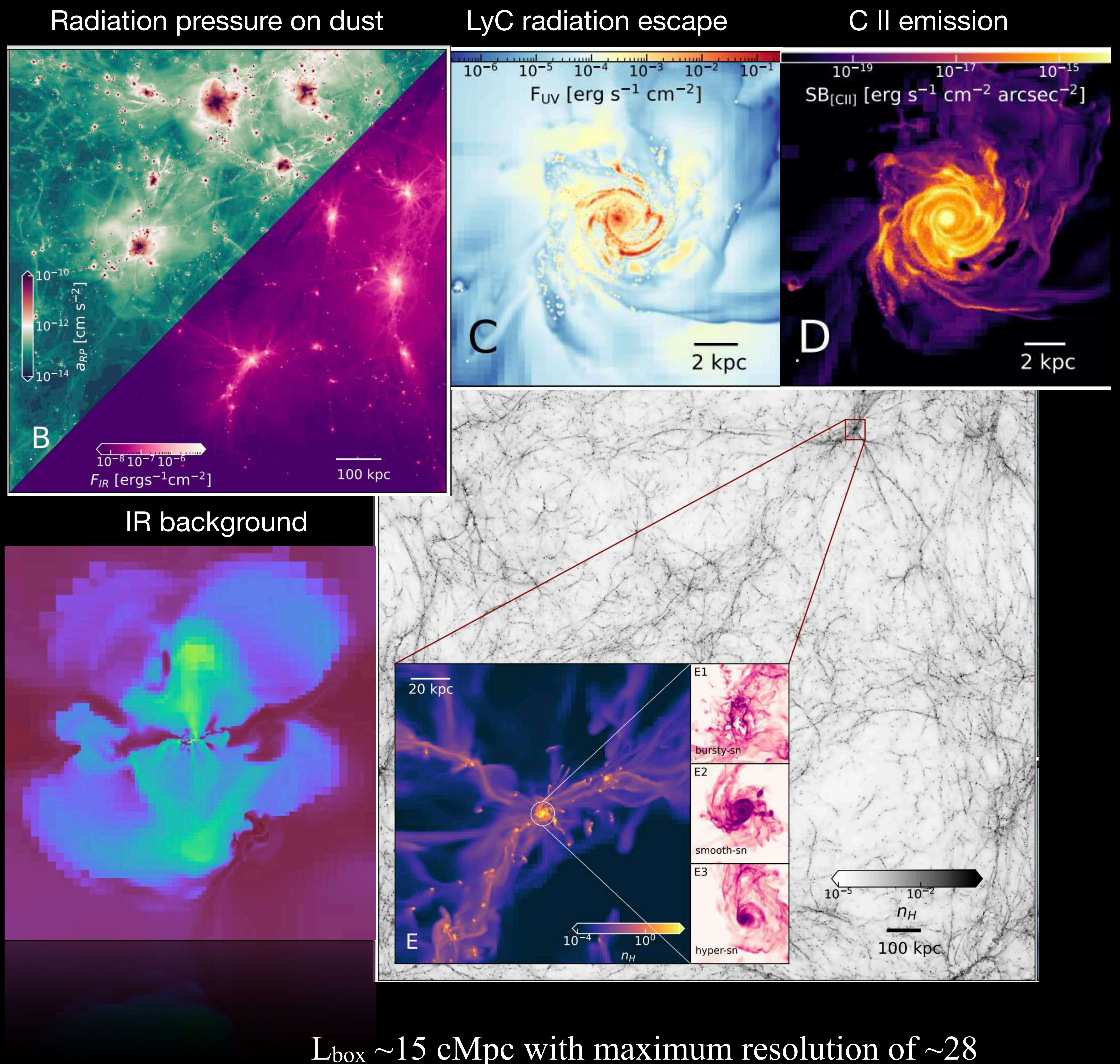
Introducing: SPICE

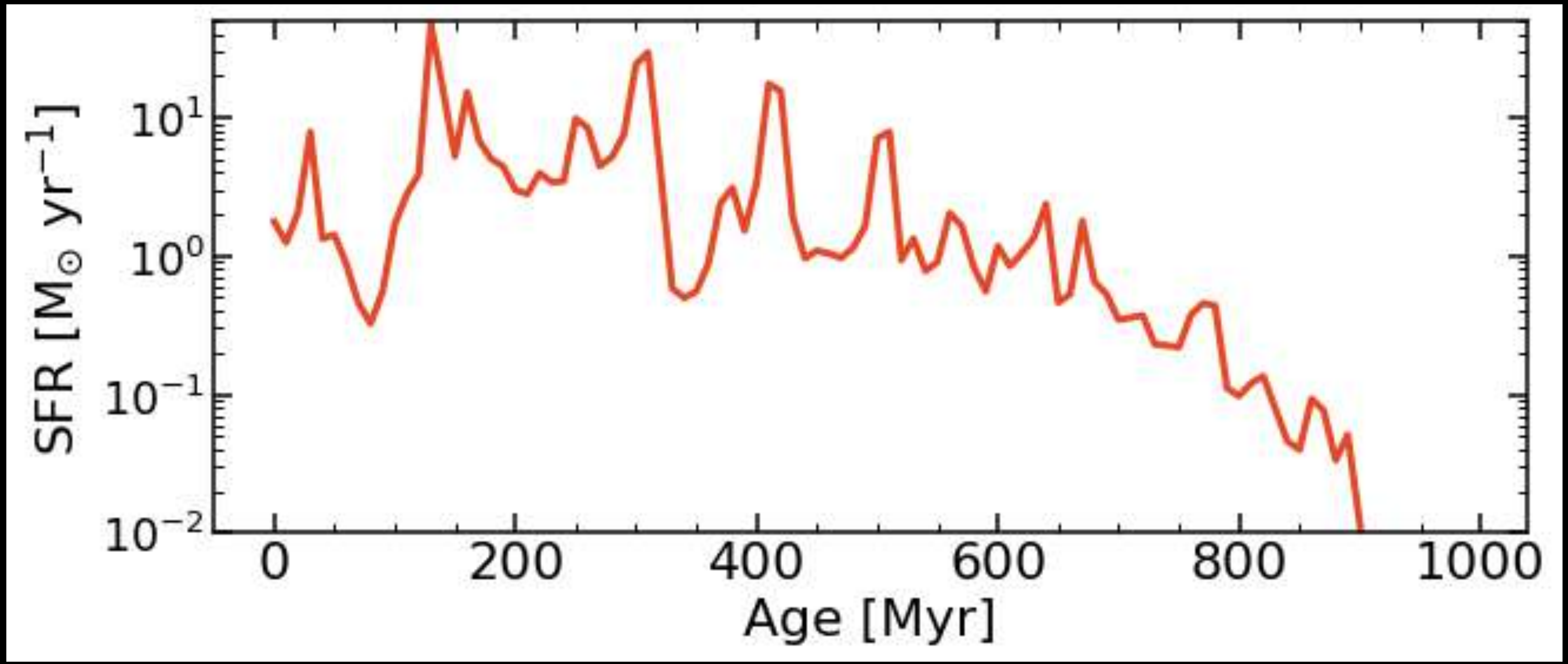
- RAMSES-RT (Rosdahl et al. 2013, Rosdahl & Teyssier 2015)
- Non-equilibrium thermochemistry of HI, HeII, HeIII fully coupled to the local radiation field
- Self consistent radiation transport: 5 radiation groups: IR, optical, 3 UV with a subgrid dust model
- Star formation based on a SGS turbulence model (Kretschmer & Teyssier 2020)
- Mechanical supernova feedback (Kimm & Cen 2014) with a new variable SN II and hypernova implementation: **3 SN feedback behaviours**



L_{box} ~15 cMpc with maximum resolution of ~28 pc (~15 pc) at z = 5 (10)

Supernova feedback variations: “bursty-sn”

- Single SN event per stellar particle at 10 Myr after birth
- Energy per individual SN, $E_{\rm SNII} = 2 \times 10^{51} {\rm erg}$
- Produces consistently bursty star formation histories

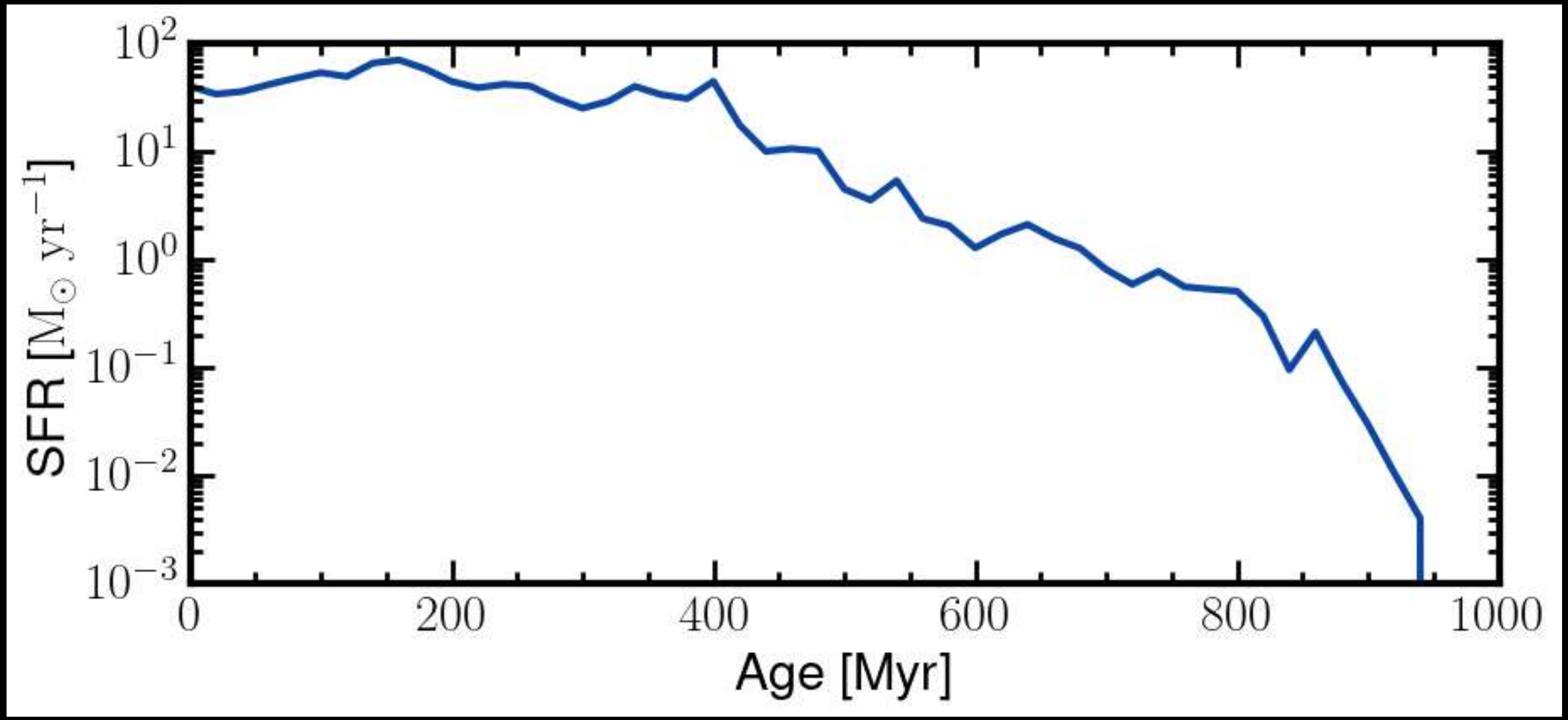


“IMF averaged” model

Supernova feedback variations: “smooth-sn”

- Realistic SN delay time distribution
  $t_{\mathrm{SNII}} = 3 - 40$ Myr

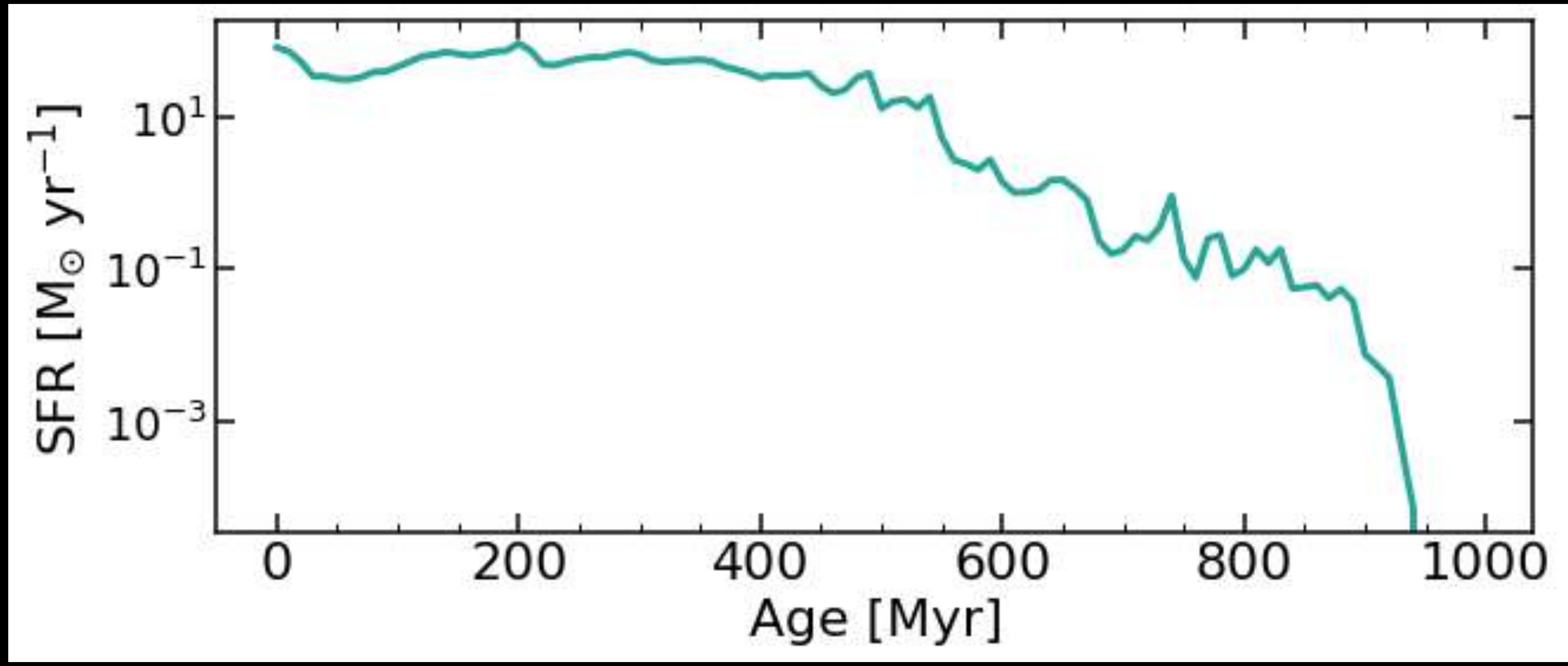
- Starbursts largely induced by mergers



More physically motivated as compared to bursty-sn

Supernova feedback variations: “hyper-sn”

- Initially resembles bursty-sn but evolves off to resemble smooth-sn



smooth-sn

Variable SN energies

Metallicity dependant hypernova rate

Variable ejecta masses

$E_{SNII} = 10^{50} - 2 \times 10^{51}$
Sukhbold et al. 2015

$f_{HN} = \max(0.5e^{-Z/0.001}, 0.01)$

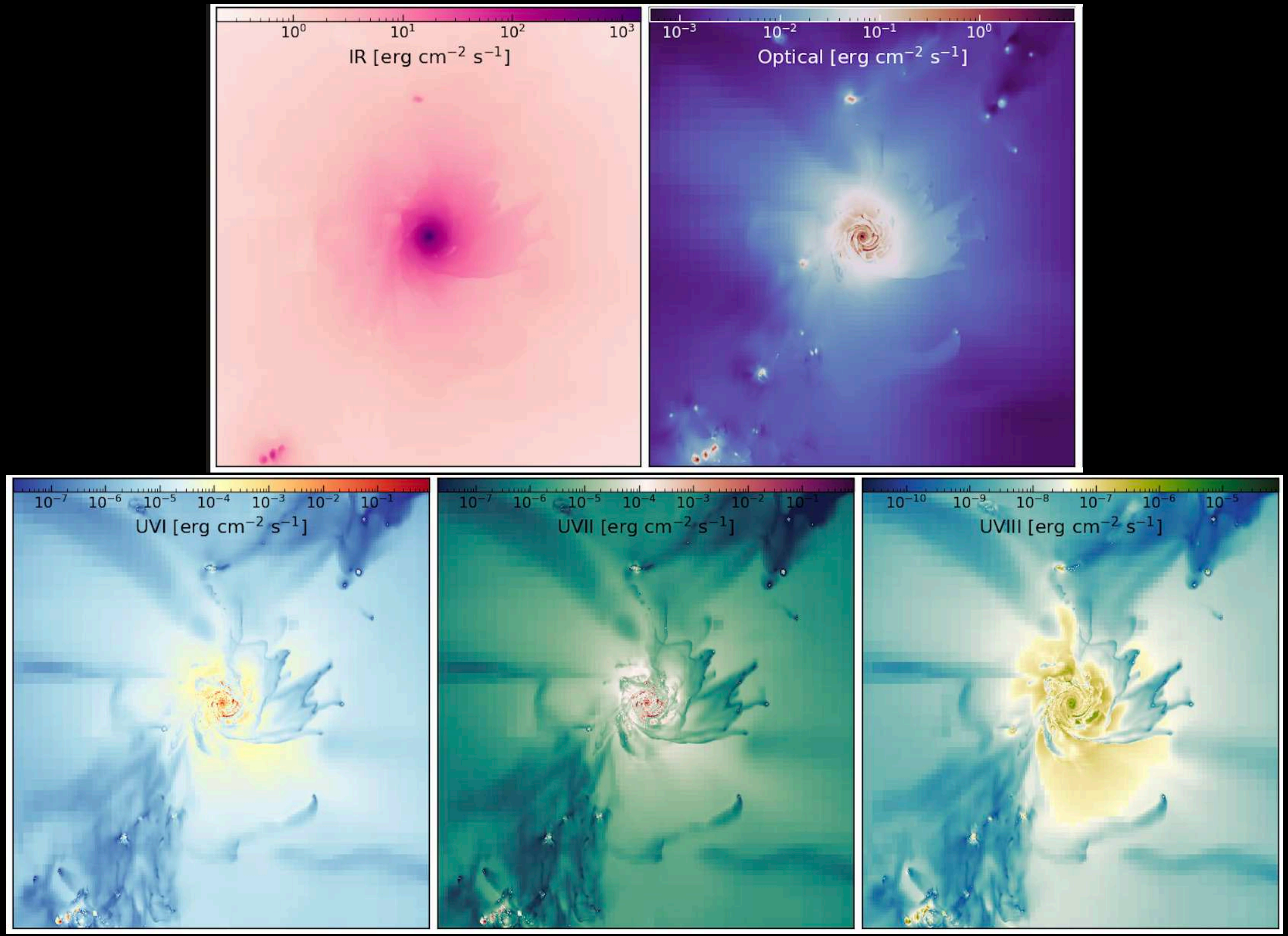
Progenitor masses between 8-40 $M_\odot$

Step by step moving towards a more physically motivated model

Stellar radiative feedback

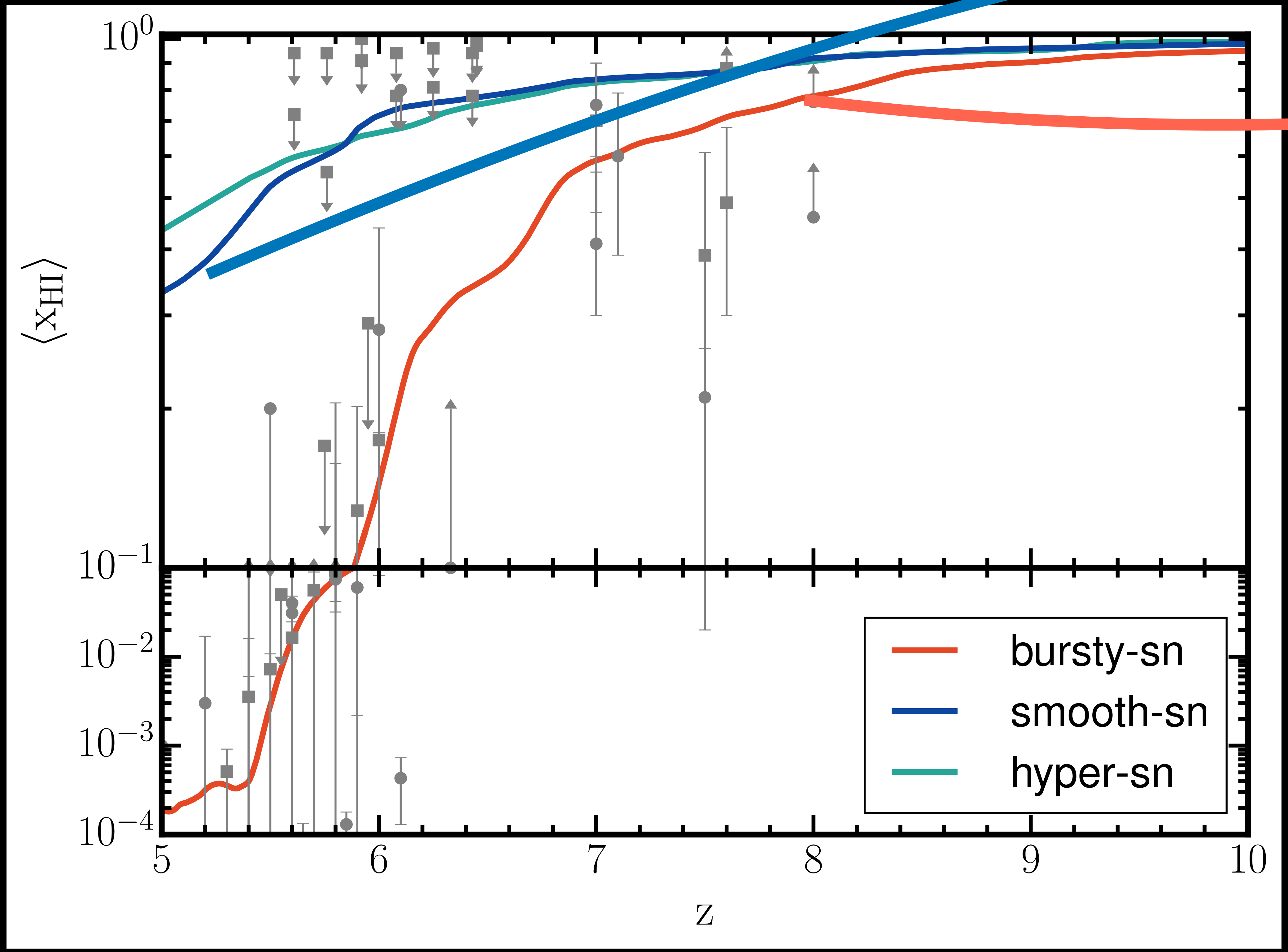
- Radiation transport in 5 frequency groups: Infrared, Optical and 3 UV groups

- **Feedback channels include**:
  - Photo-ionization
  - Photo-heating
  - Radiation pressure on dust



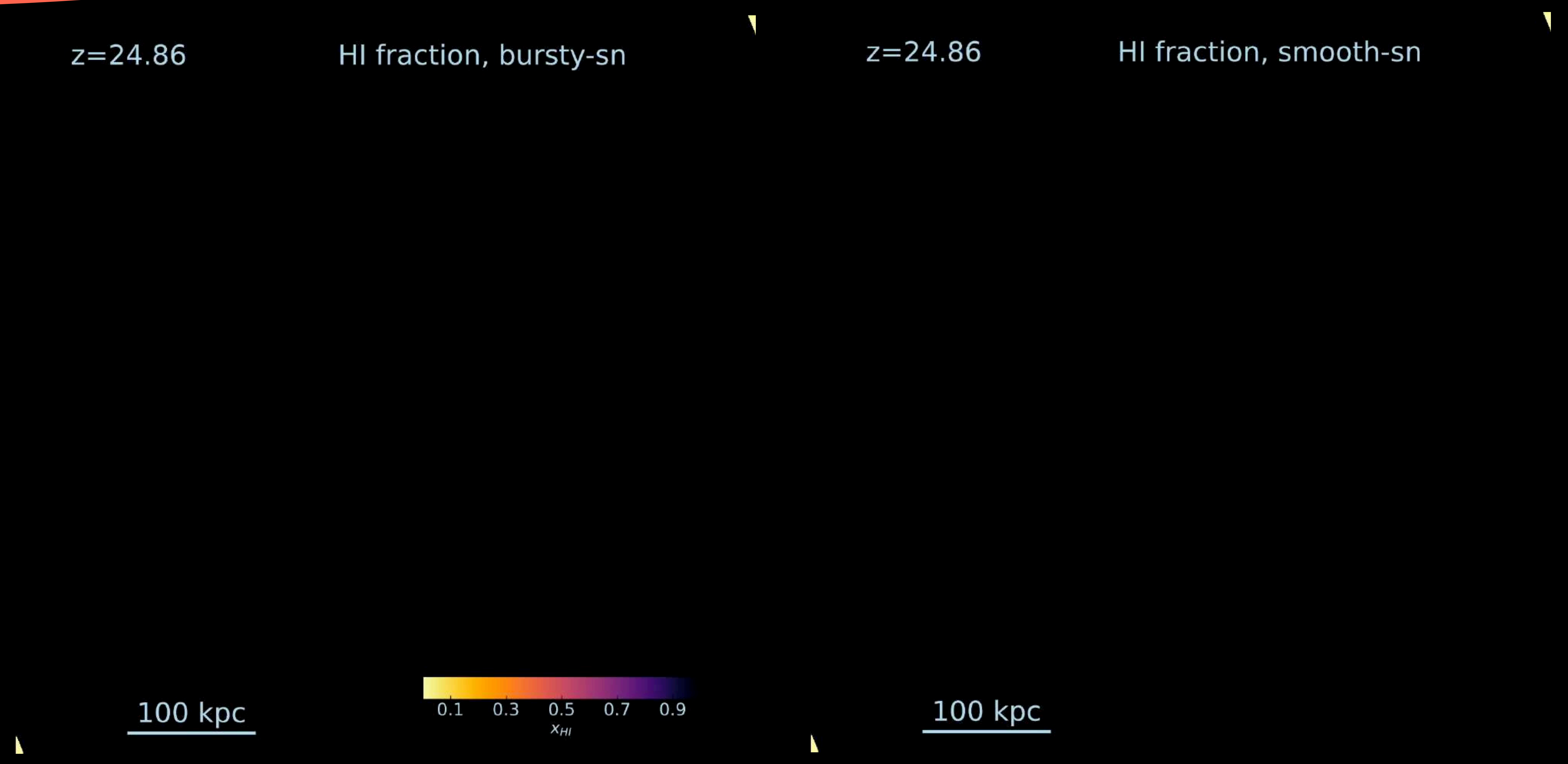
Different information from different bands

Reionisation history



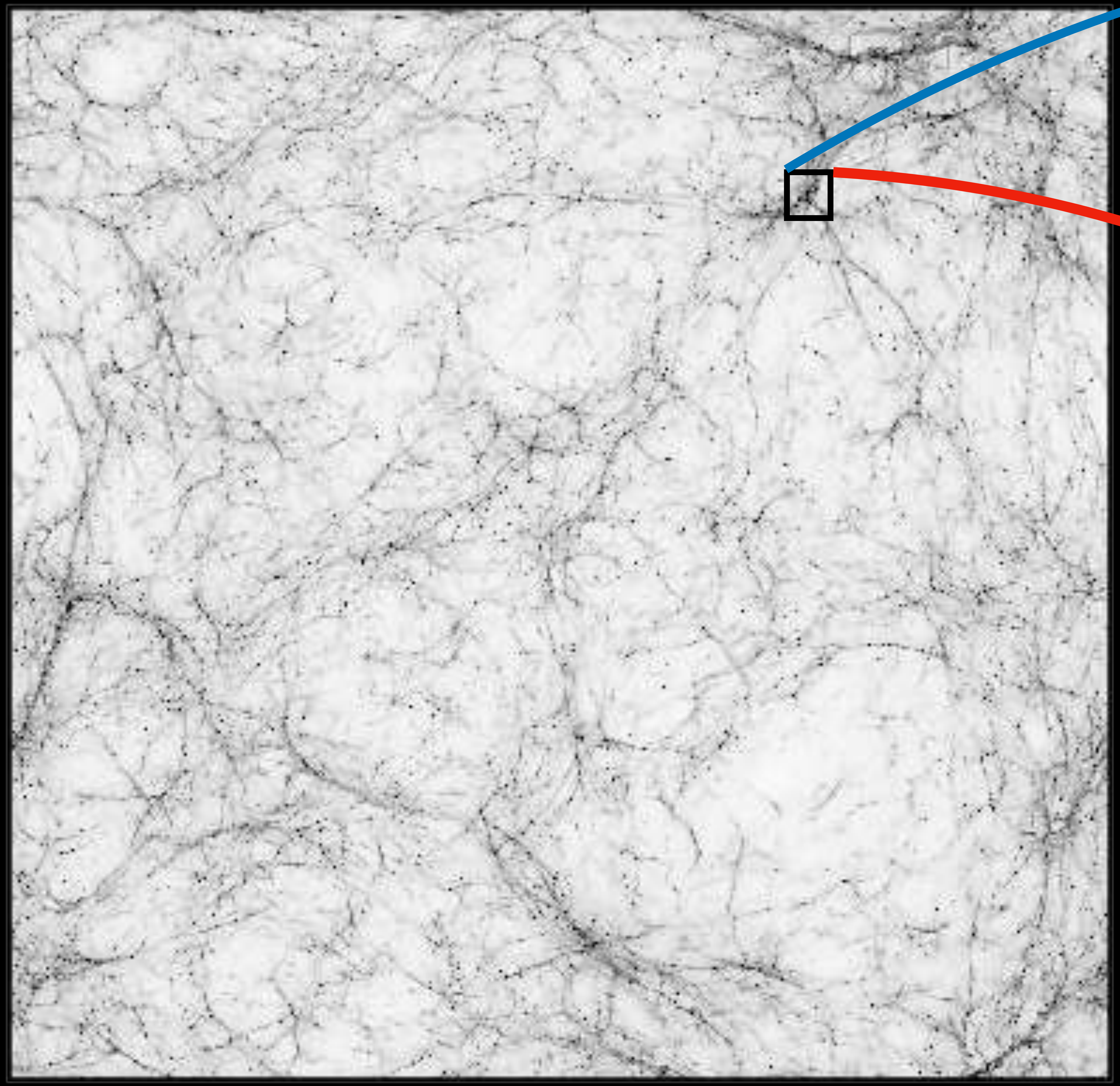
"Bursty"

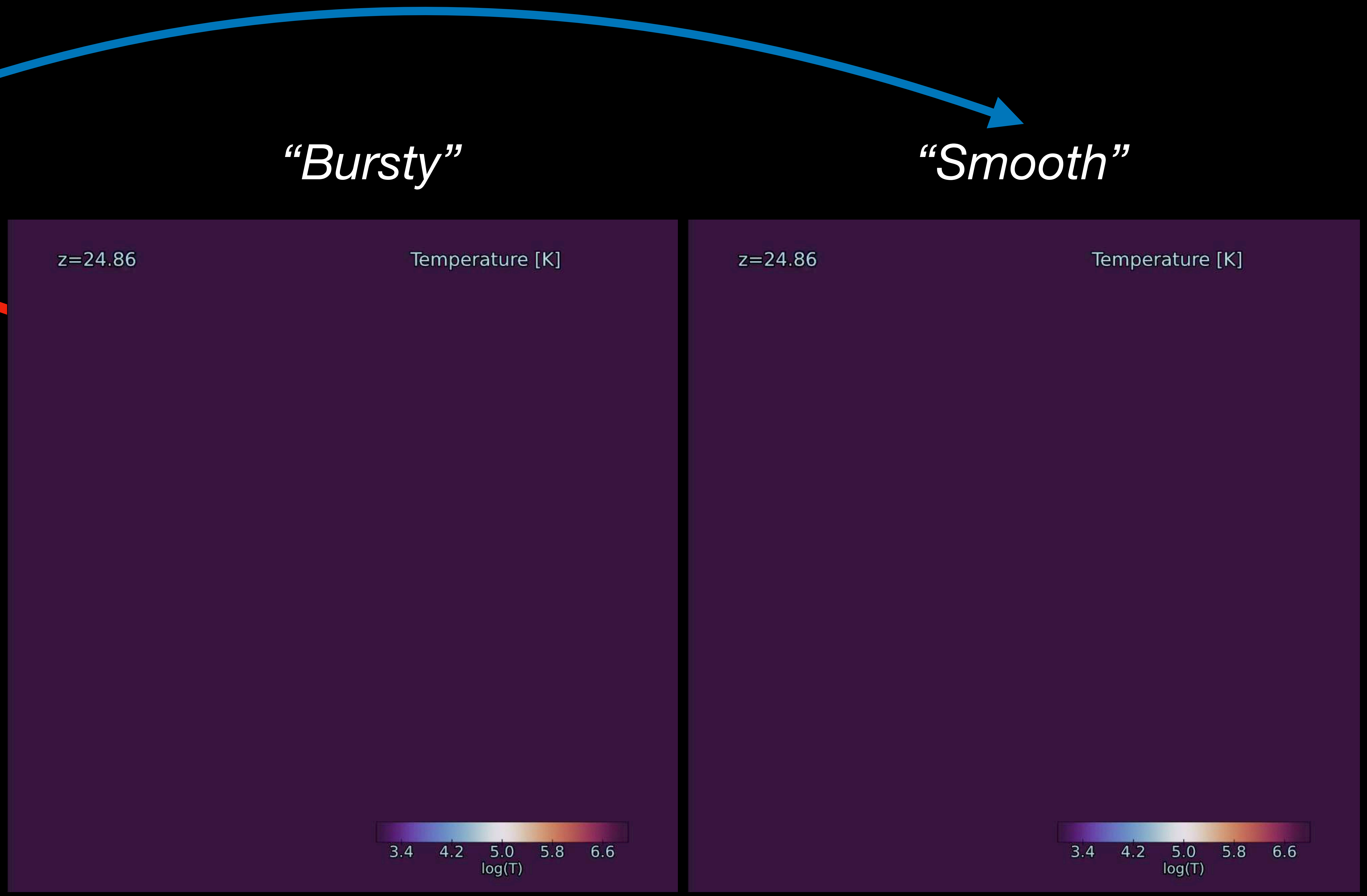
"Smooth"



Reionisation history is sensitive to the mode of SN feedback.

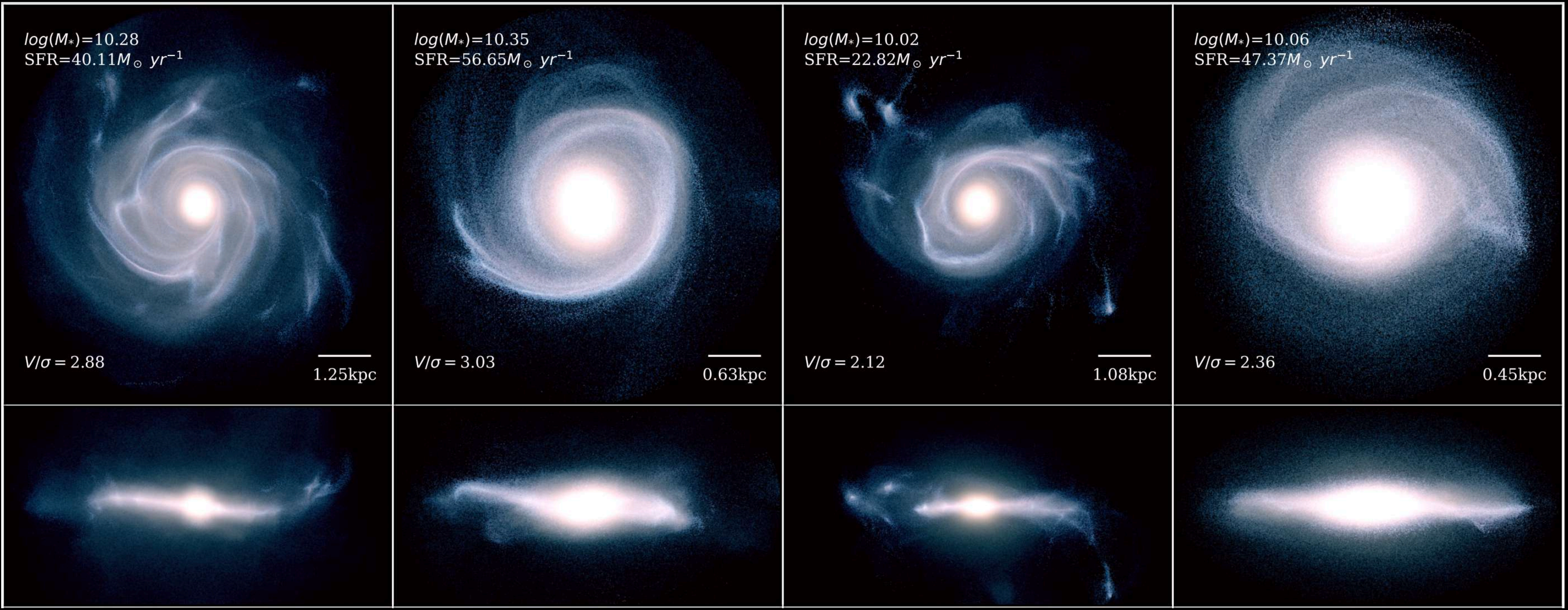
Phase structure of a halo at z=5





Phase structure of a halo systematically affected by different SN behaviour

Morphologies: A key observable

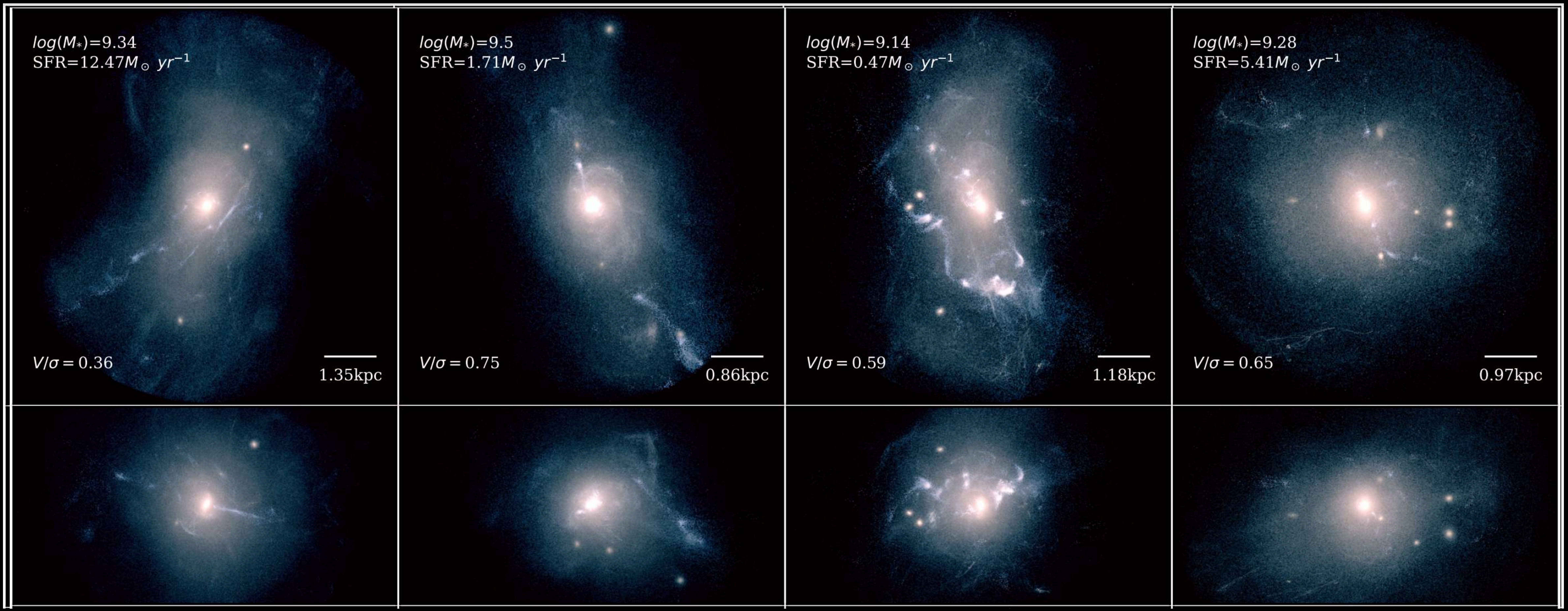


Reionisation incomplete by z=5

Smooth SN: Rotation supported galaxies

JWST : F200W+F277W+F444W

Morphologies: A key observable

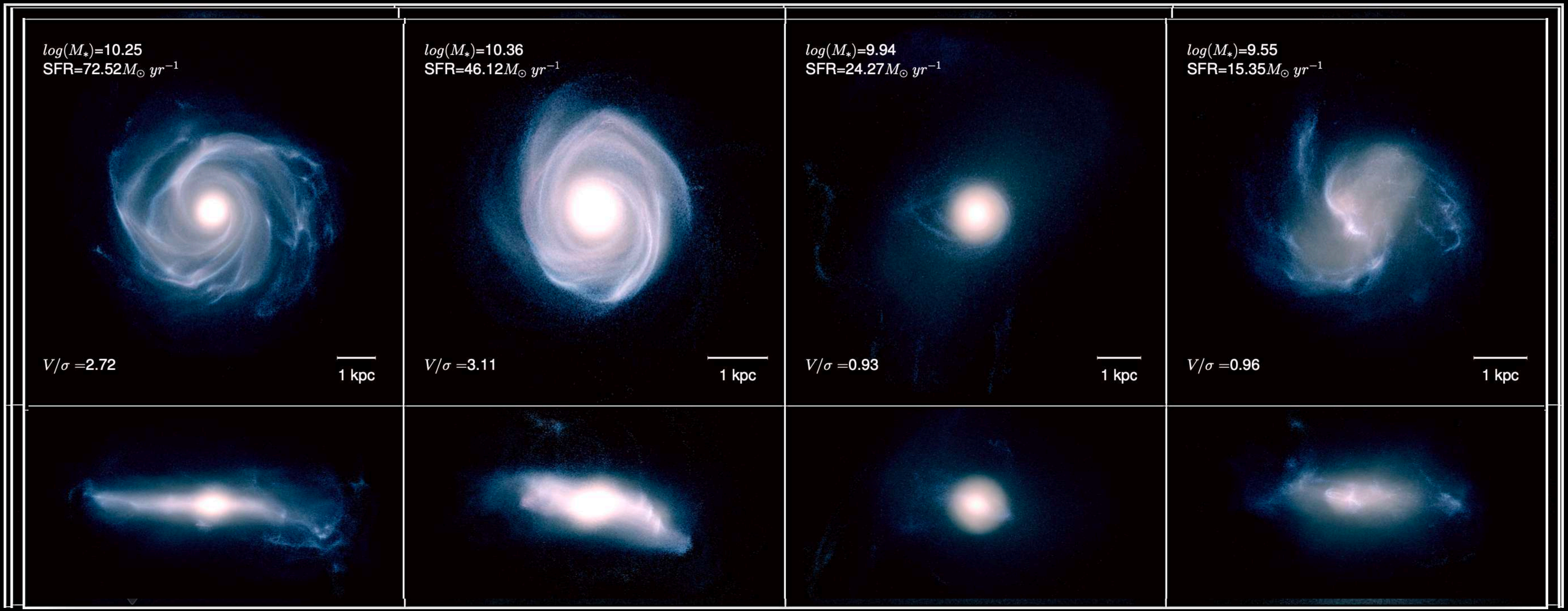


Reionization complete by z=5

Bursty SN: Dispersion supported galaxies

JWST : F200W+F277W+F444W

Morphologies: A key observable

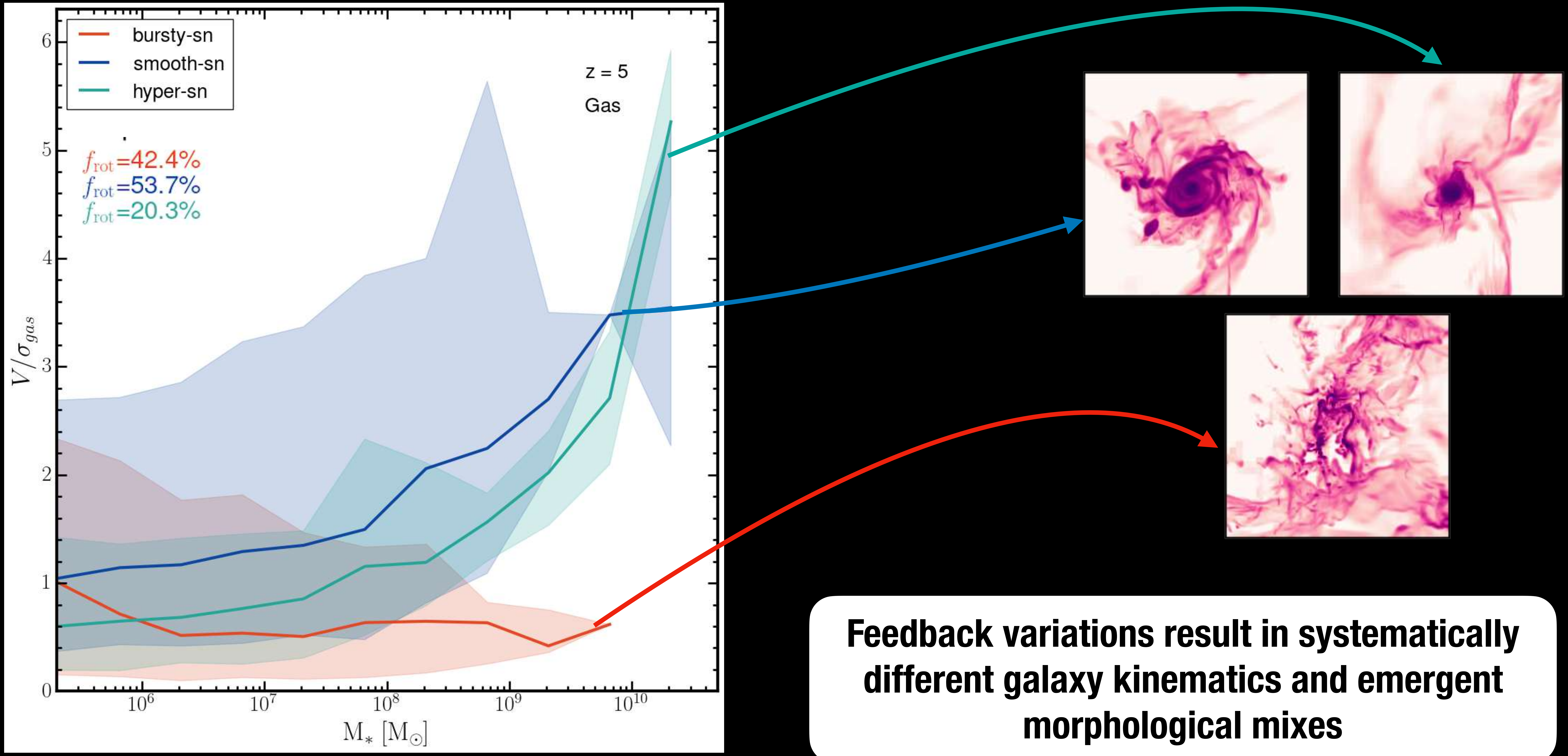


Reionisation incomplete by z=5

Hyper SN: A mix of rotation and dispersion

JWST : F200W+F277W+F444W

Morphologies: A key observable

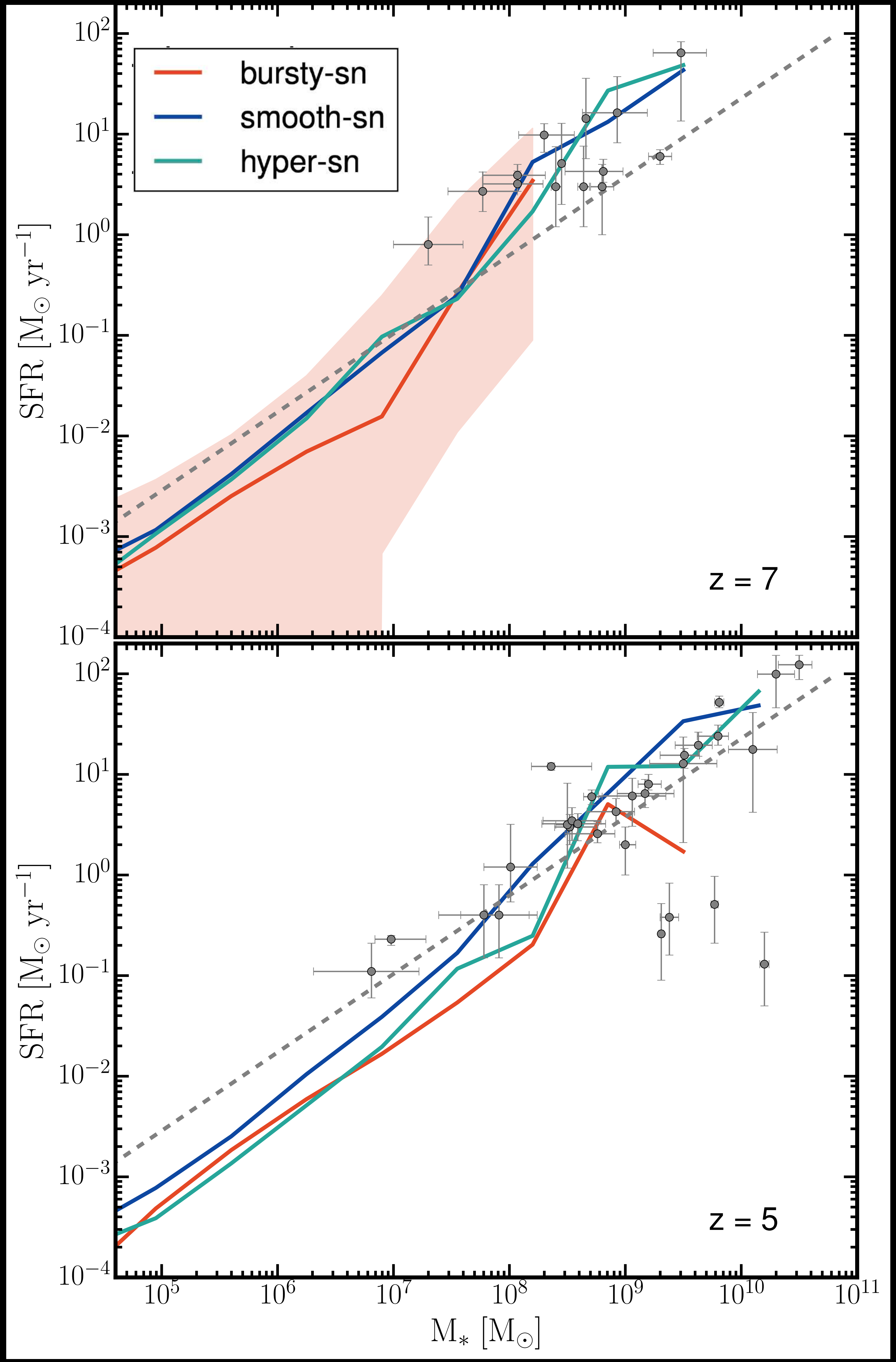


Feedback variations result in systematically different galaxy kinematics and emergent morphological mixes

Star formation main sequence (SFMS)

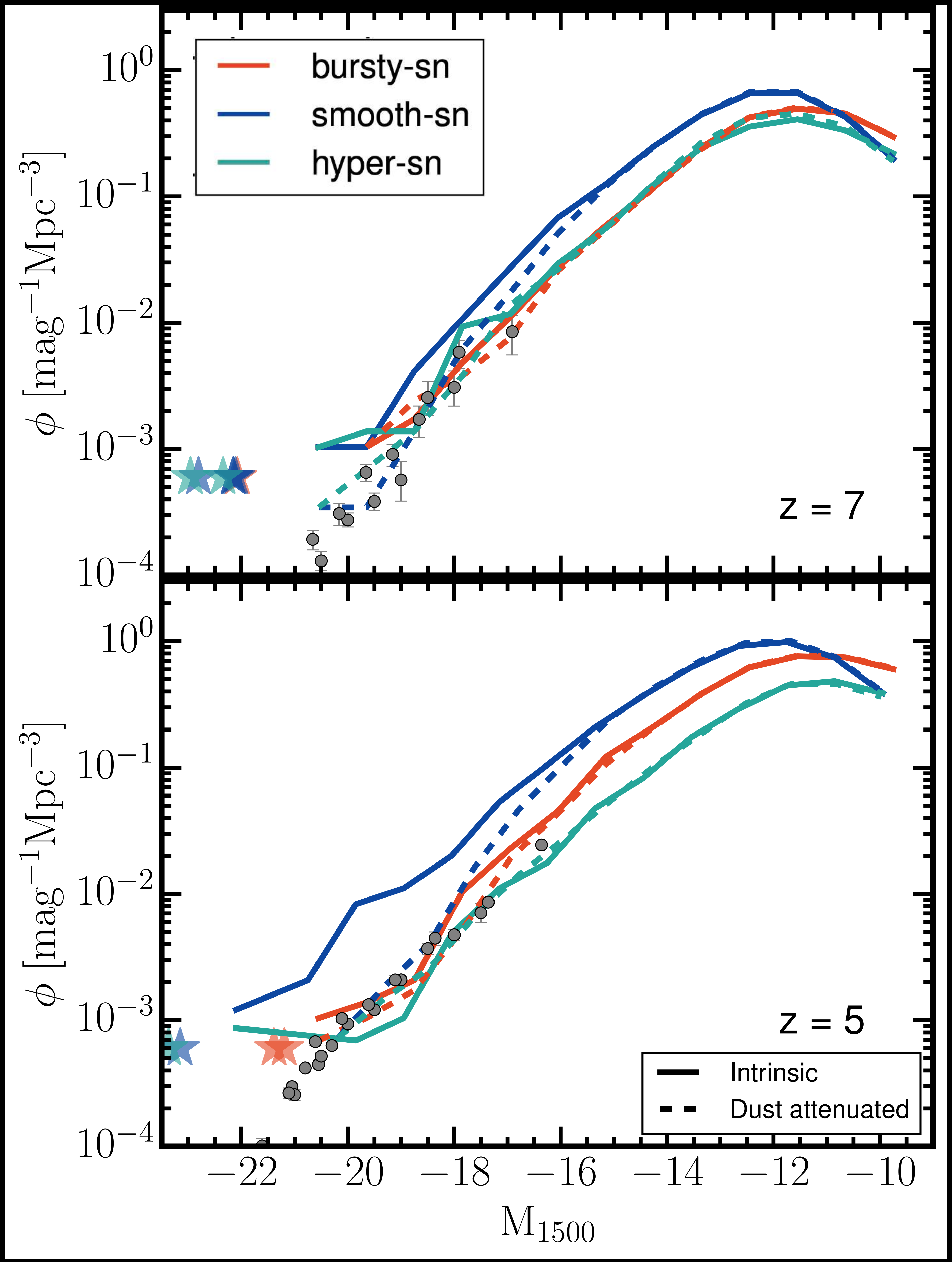
- SFRs calculated over last 10 Myr intervals
- A main sequence naturally emerges and all models show excellent agreement with JWST/HST observations

Observed star formation main sequence *cannot* be used to differentiate between models



UV luminosity function (UVLF)

- Intrinsic LFs look very similar at z=7 but show differences by z=5
- Dust attenuated LFs are identical below $M_{1500} < -16$

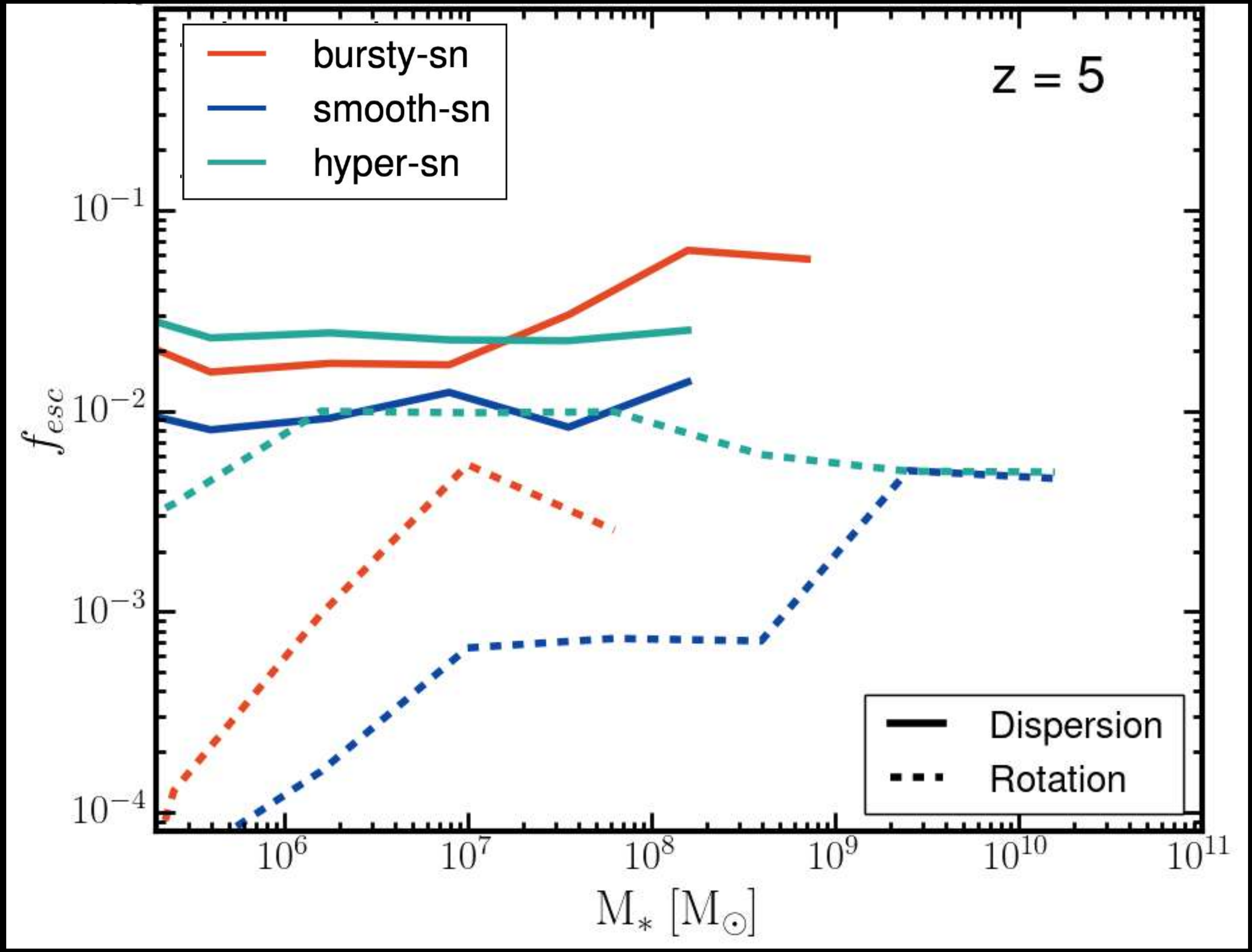


Dust attenuated luminosity functions ***cannot*** **be used to differentiate between models**

LyC escape fractions

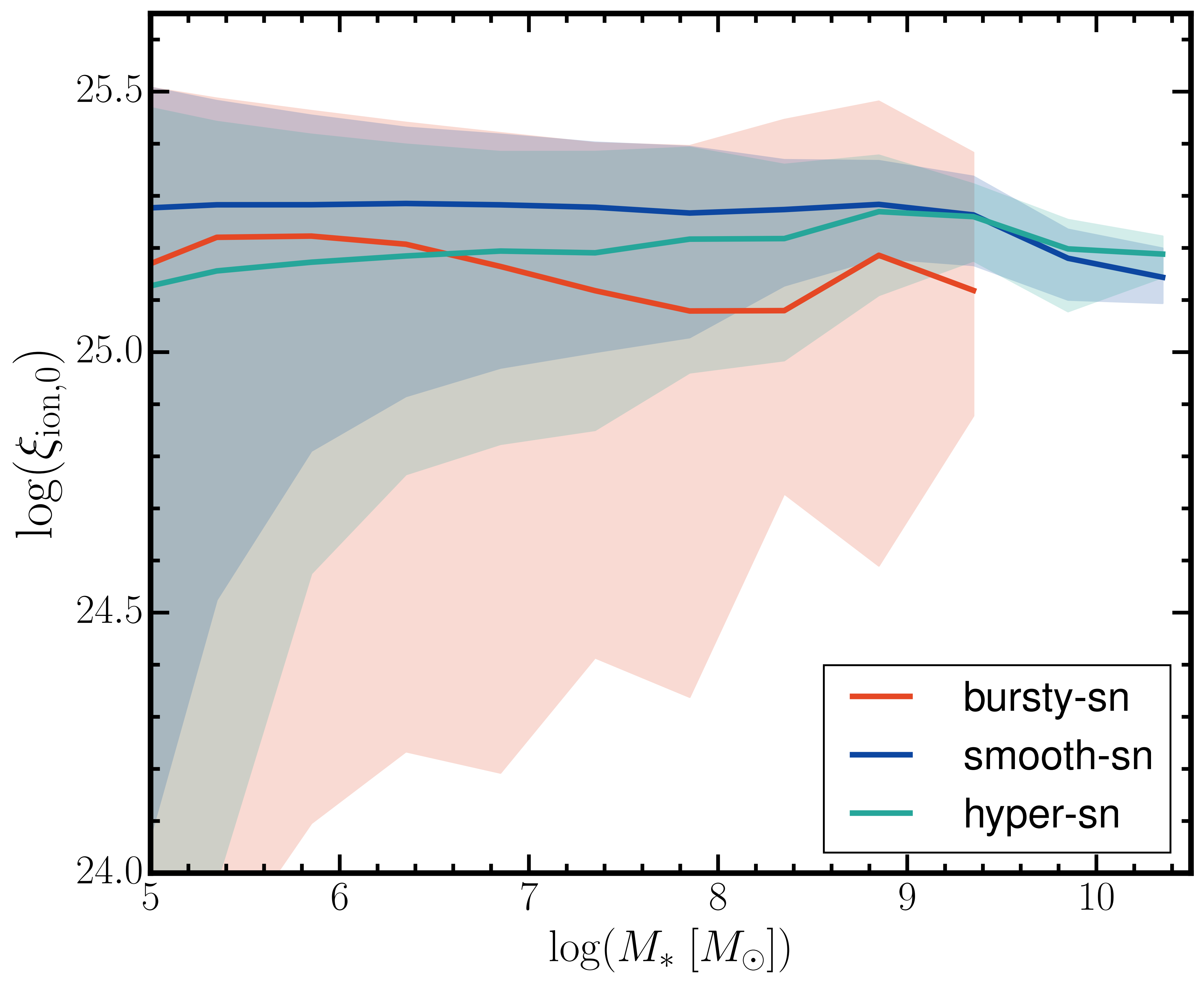
- Escape fractions computed using RASCAS by allowing propagation to viral radius
- Angle averaged escape fractions using 200 sightlines

Ionising radiation escapes more easily in disturbed systems.



Connecting to observations

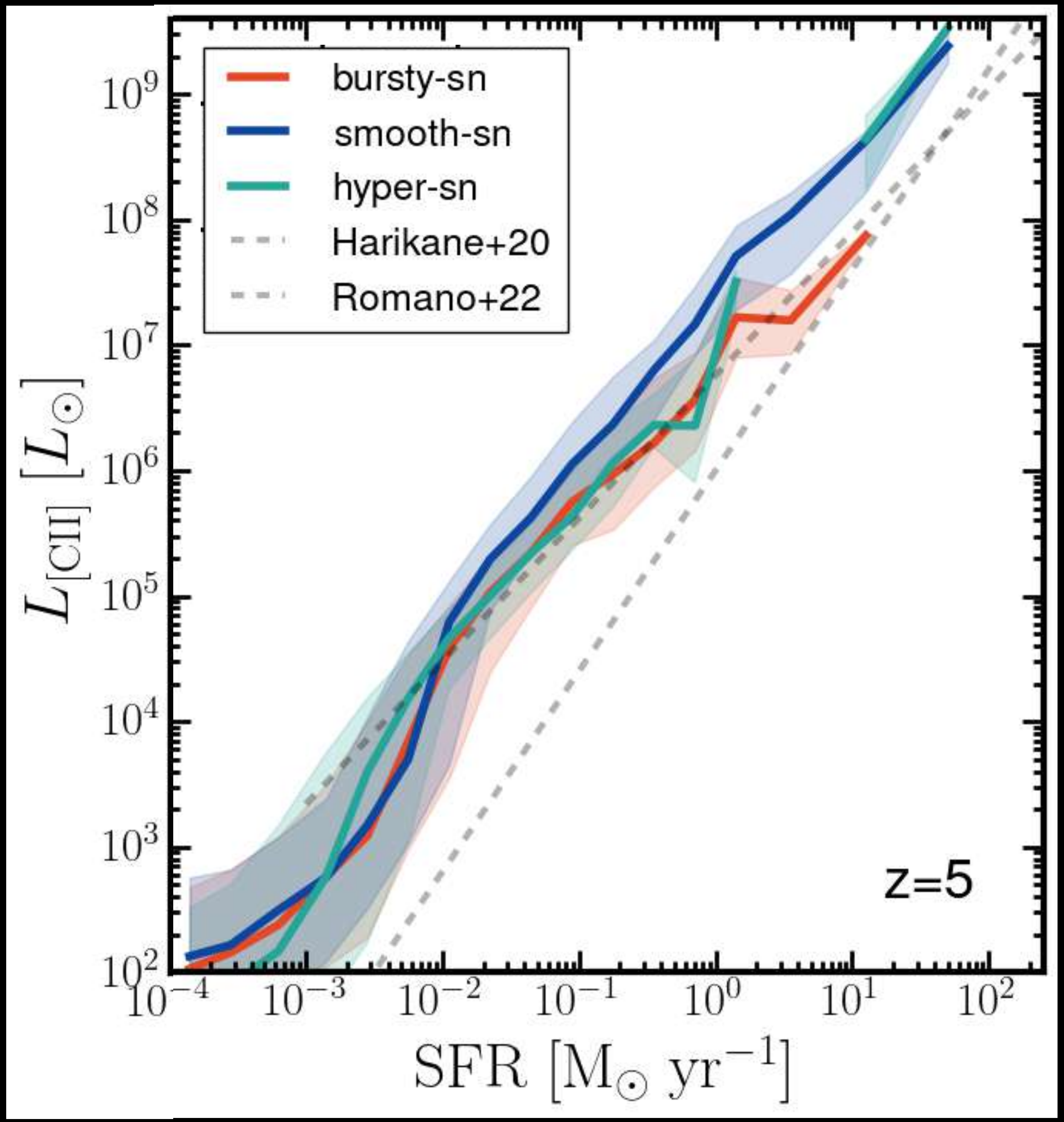
- Observations quote "Ionising photon production efficiency" to comment on galaxies that reionise the universe
- $\xi_{\text{ion},0} = \frac{\dot{N}_{\text{ion}}}{L_{1500}}$, assume $f_{\text{esc}} = 0$, therefore ***intrinsic***



All models show degenerate ionising photon production efficiency. Reionsiation is f_{esc} limited, *not* photon production limited

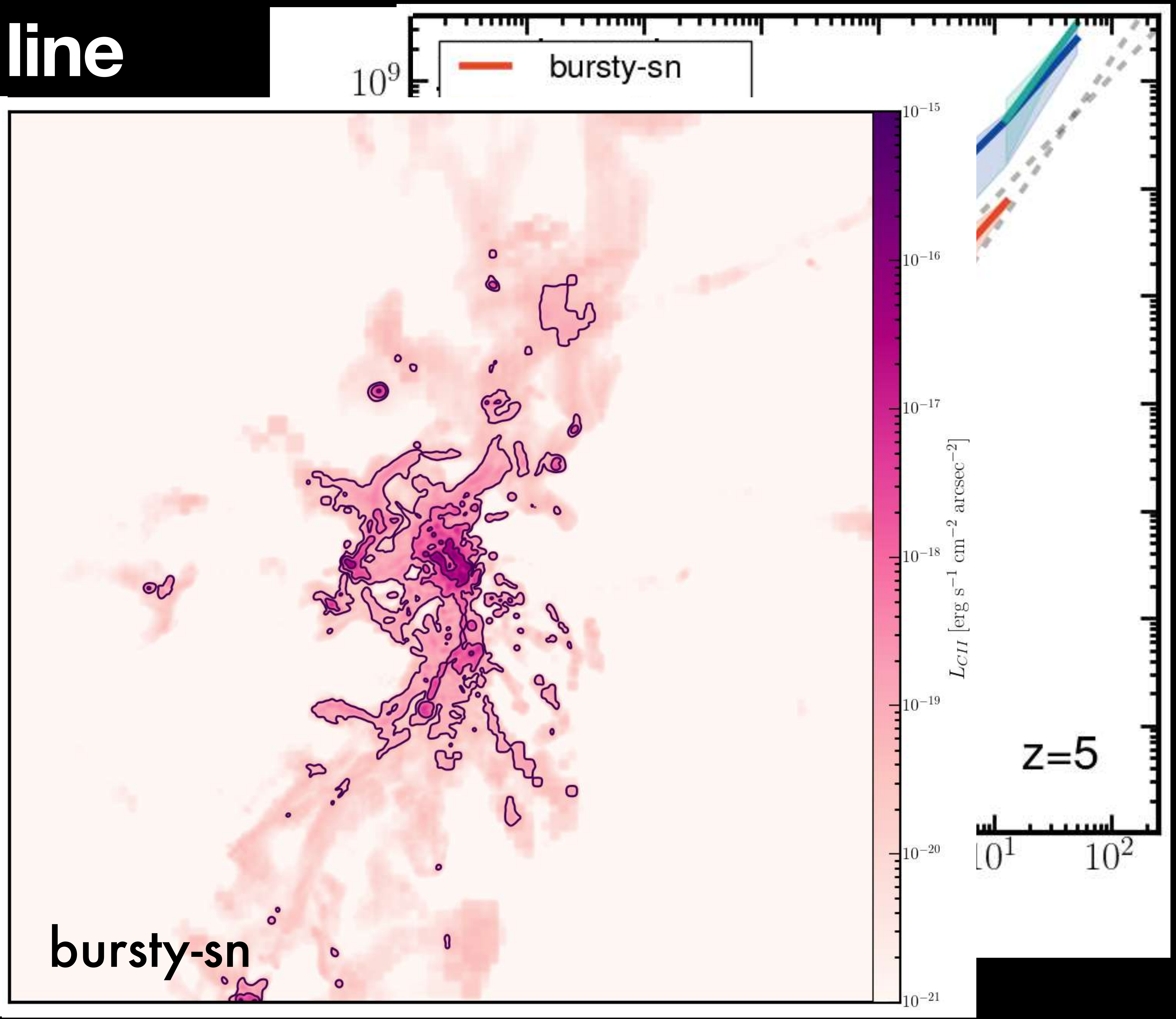
Emission line observables: [CII] line

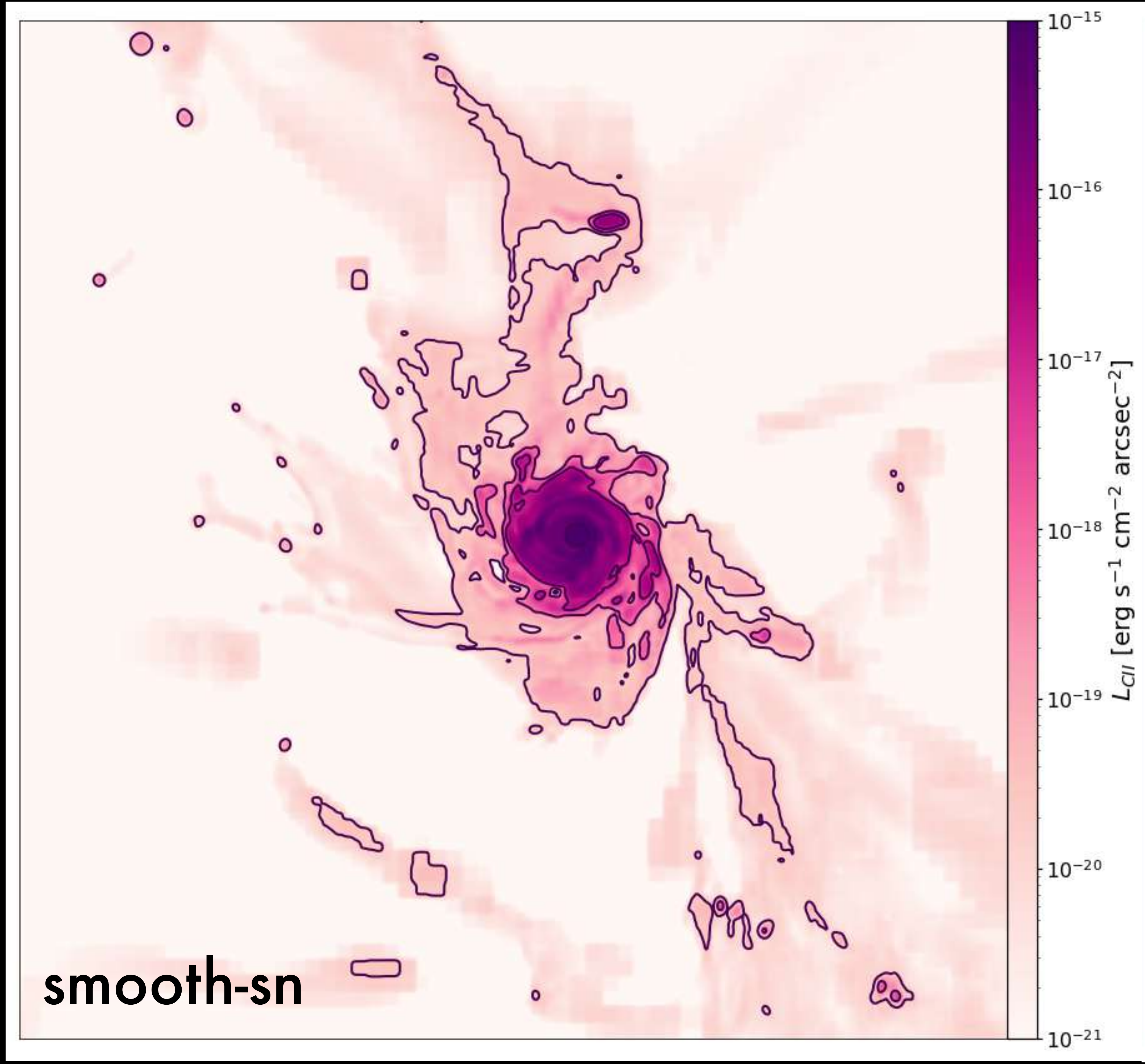
- On-the-fly RT already tracks the FUV radiation and non-equilibrium electron and HI fractions.
- Subgrid model to calculate [CII] luminosities, kinematics and synthetic observations for ALMA!



AB et al. in prep.

Emission line observables: [CII] line

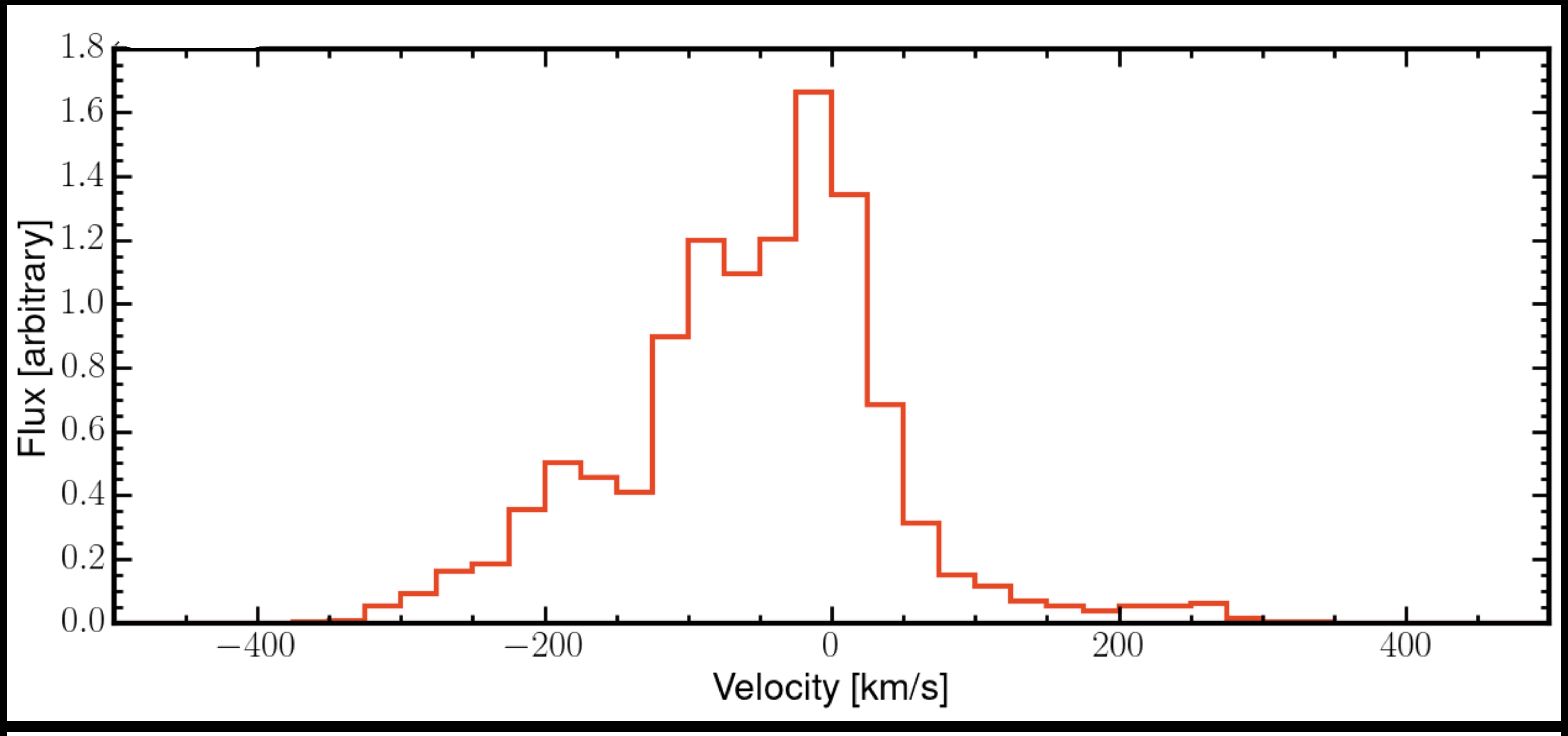


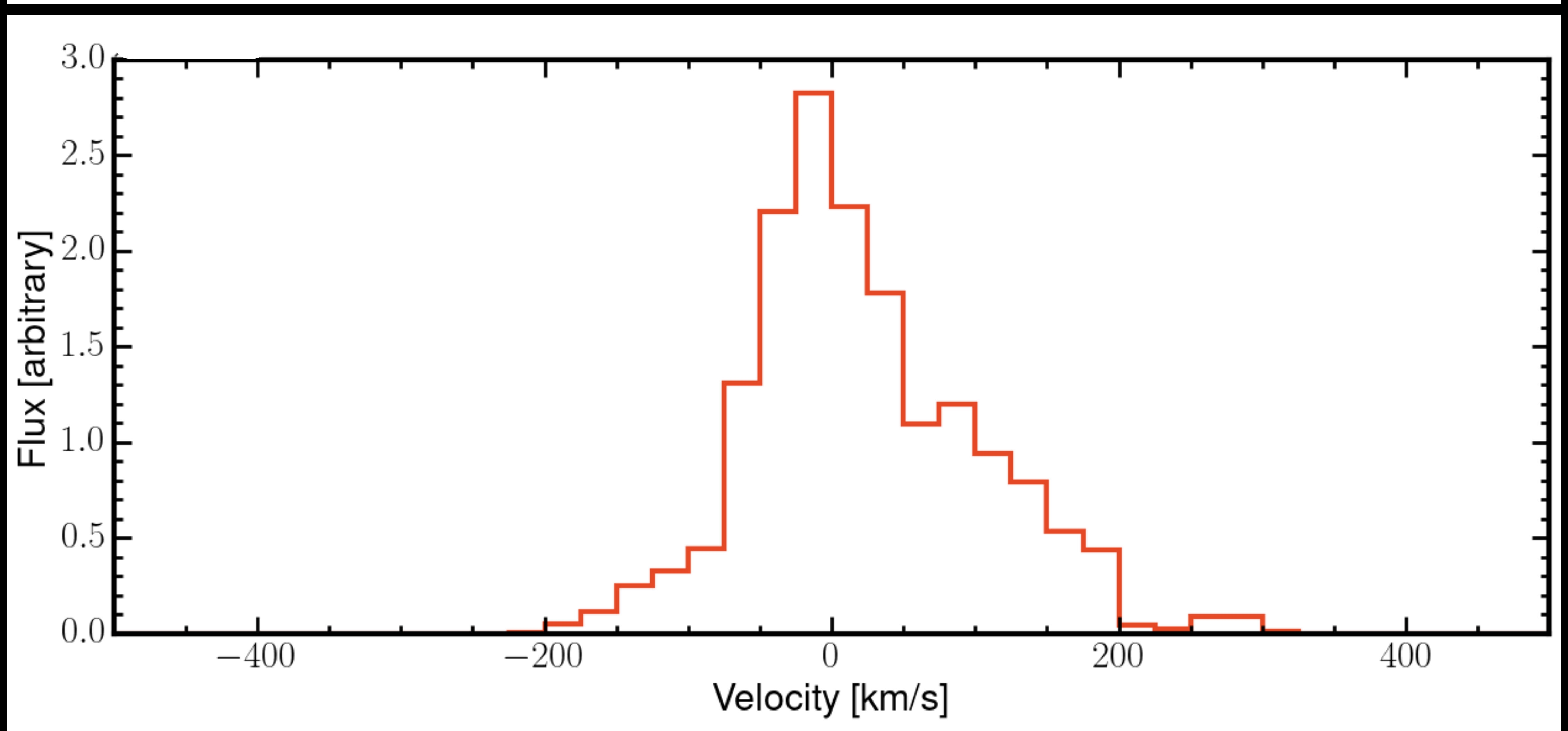


Different kinematics in [CII]

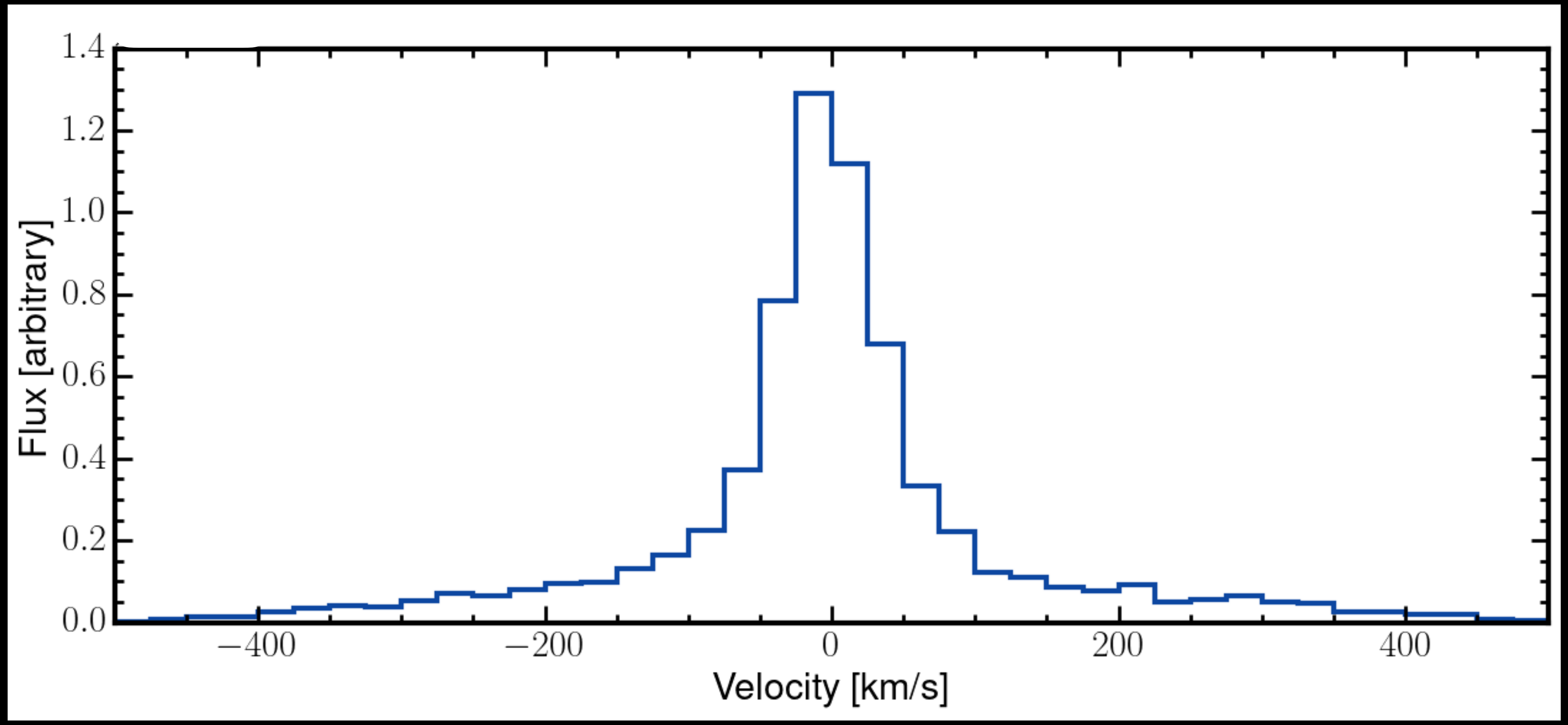
Broad [CII] lines: A tool to constrain feedback?

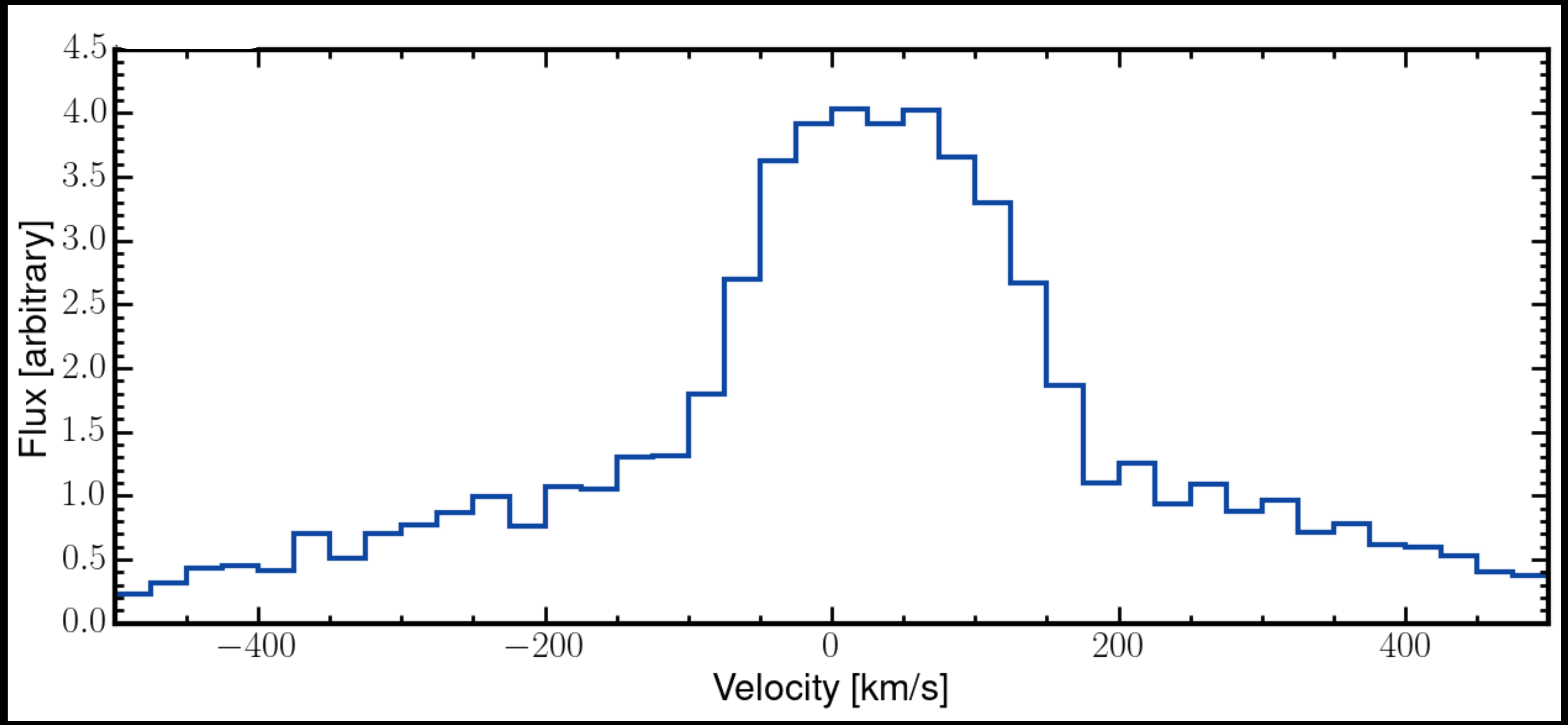
bursty-sn





smooth-sn

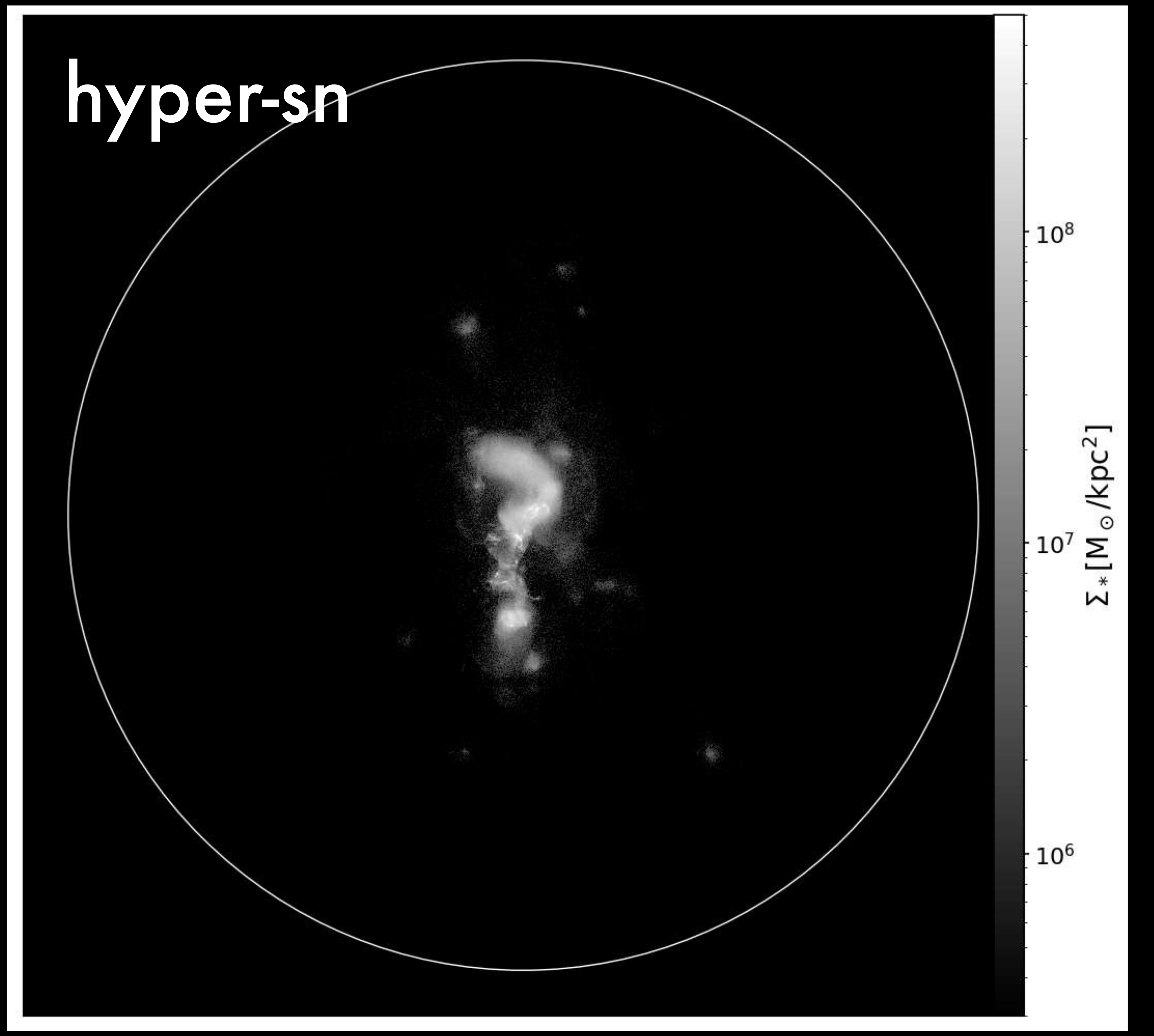




arXiv:2310.16895

Conclusions

- Properties of galaxies in different reionsiation scenarios vary dramatically in a major, systematic way
- Some galaxy observables such as SFMS/UVLF are degenerate
- Mode of feedback very strongly alters the morphological mix of galaxies that emerge *post-reionisation*
- More ionising photon production/more supernovae does not mean faster reionisation: $f_{\rm esc}$ limited reionisation!
- Observations of galaxy morphologies post reionisation will help constrain stellar feedback models at z>5
- Multi-wavelength studies are key!



$M_* = 10^{8.5} M_\odot$ at z=5.4!

THANK YOU!